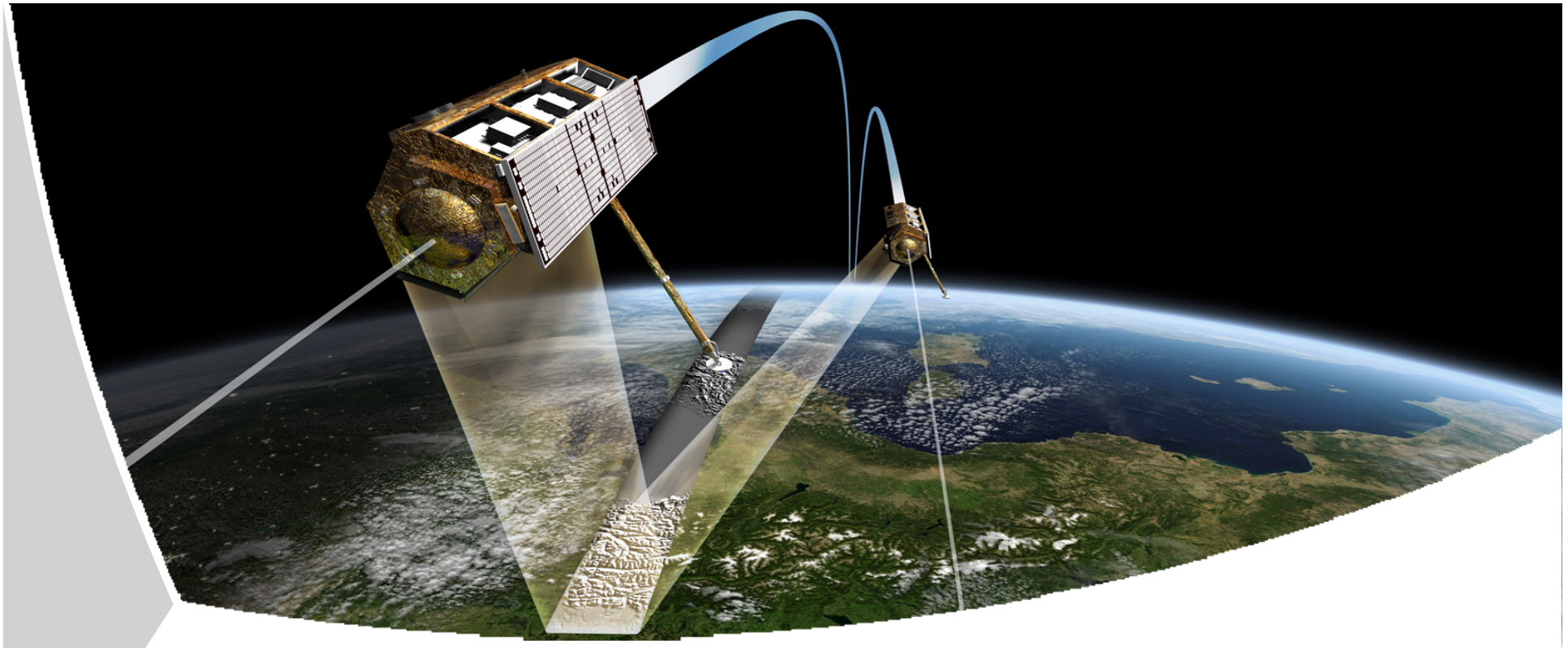


Interferometric TanDEM-X Data Processing – First Operational Experiences

T. Fritz, H. Breit, B. Schättler, U. Balss, C. Rossi, A. Niedermeier, M. Schwinger

CEOS SAR Calibration and Validation Workshop

Fairbanks, Alaska, November 07 – 09, 2011

DLR Deutsches Zentrum für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft

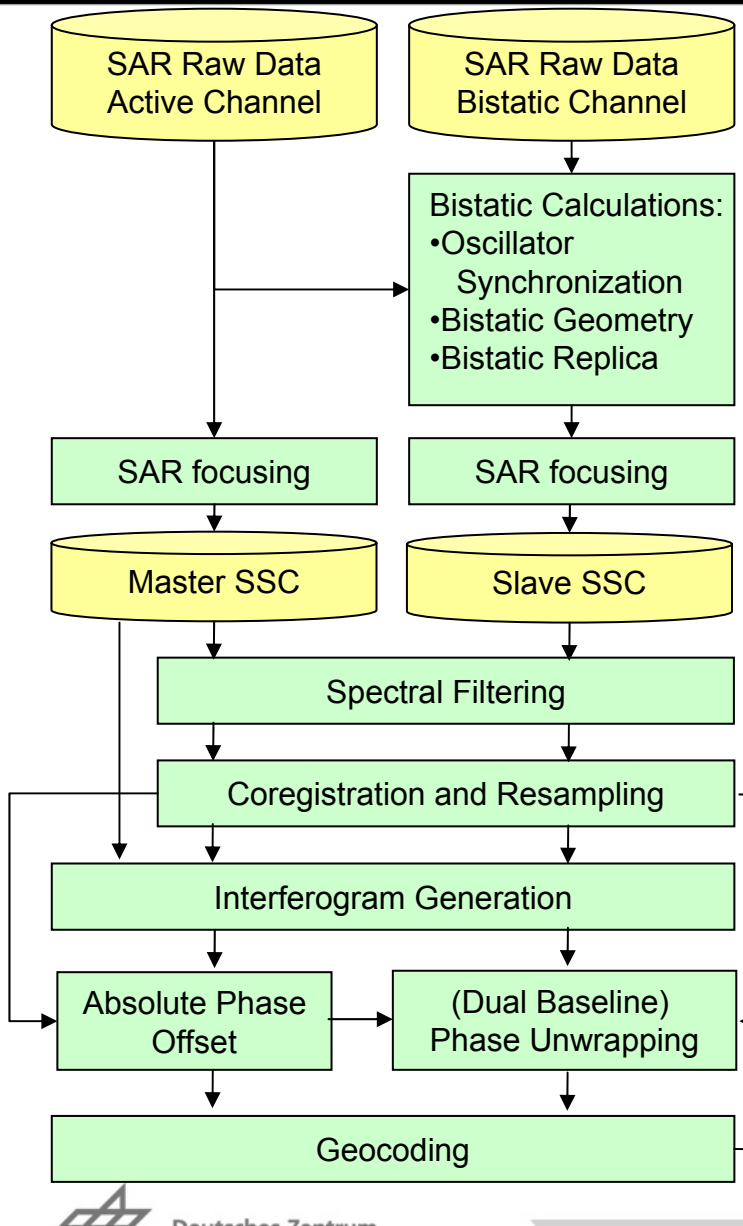
TanDEM

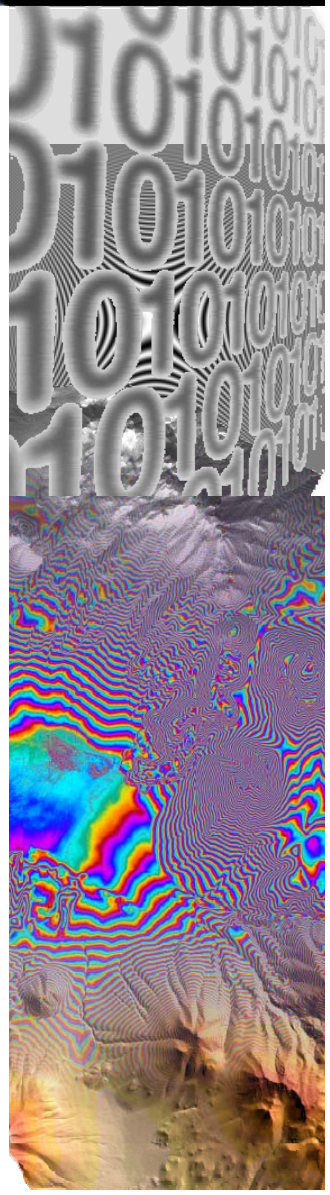
Outline

- Integrated TanDEM-X processor (ITP) overview
- Bistatic processing challenges: oscillator and data take start time synchronization
- InSAR processing highlights
- High throughput and quality control
- ITP production and quality data base

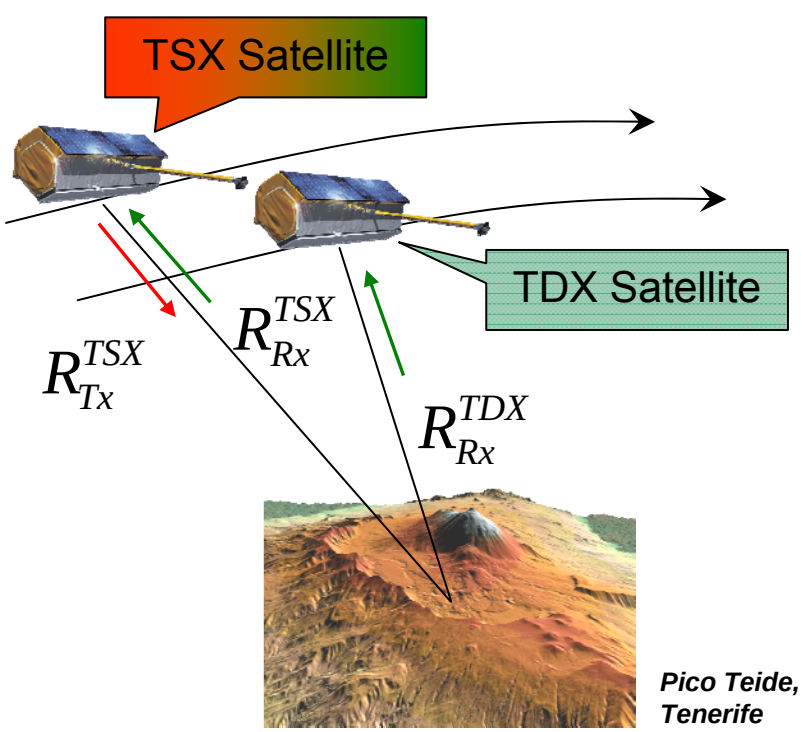
The Integrated TanDEM-X Processor (ITP)

From Instrument Raw Data to Raw DEMs



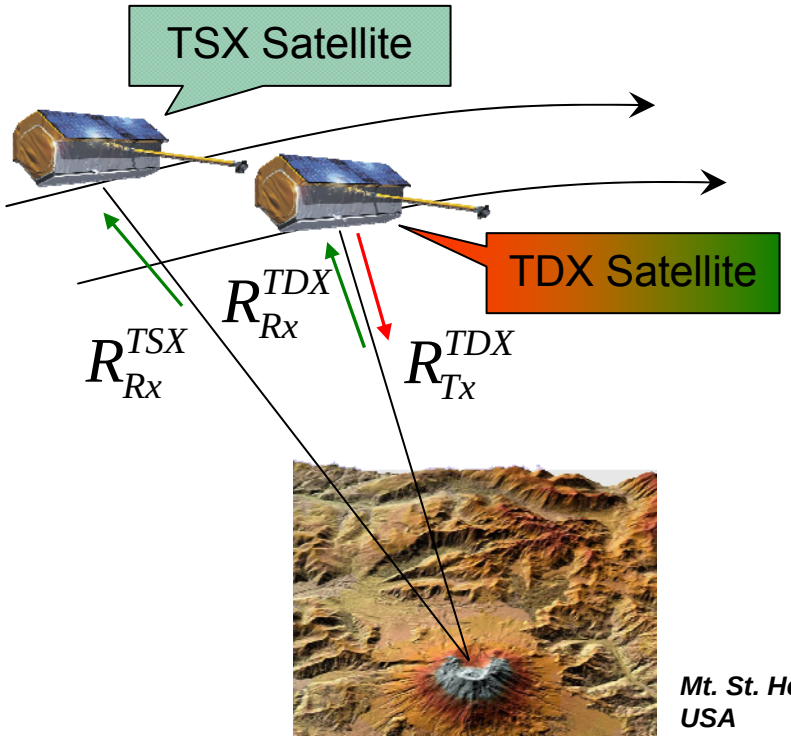


Bistatic TanDEM-X Acquisitions



Pico Teide, Tenerife

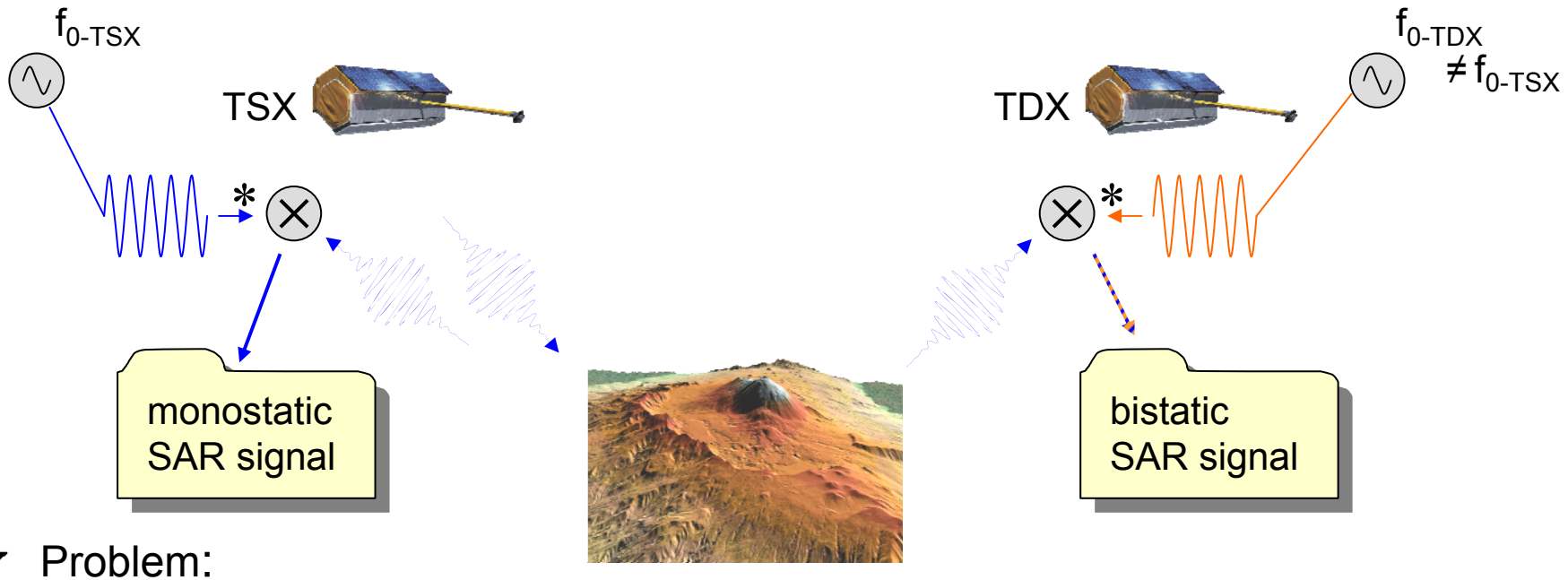
or



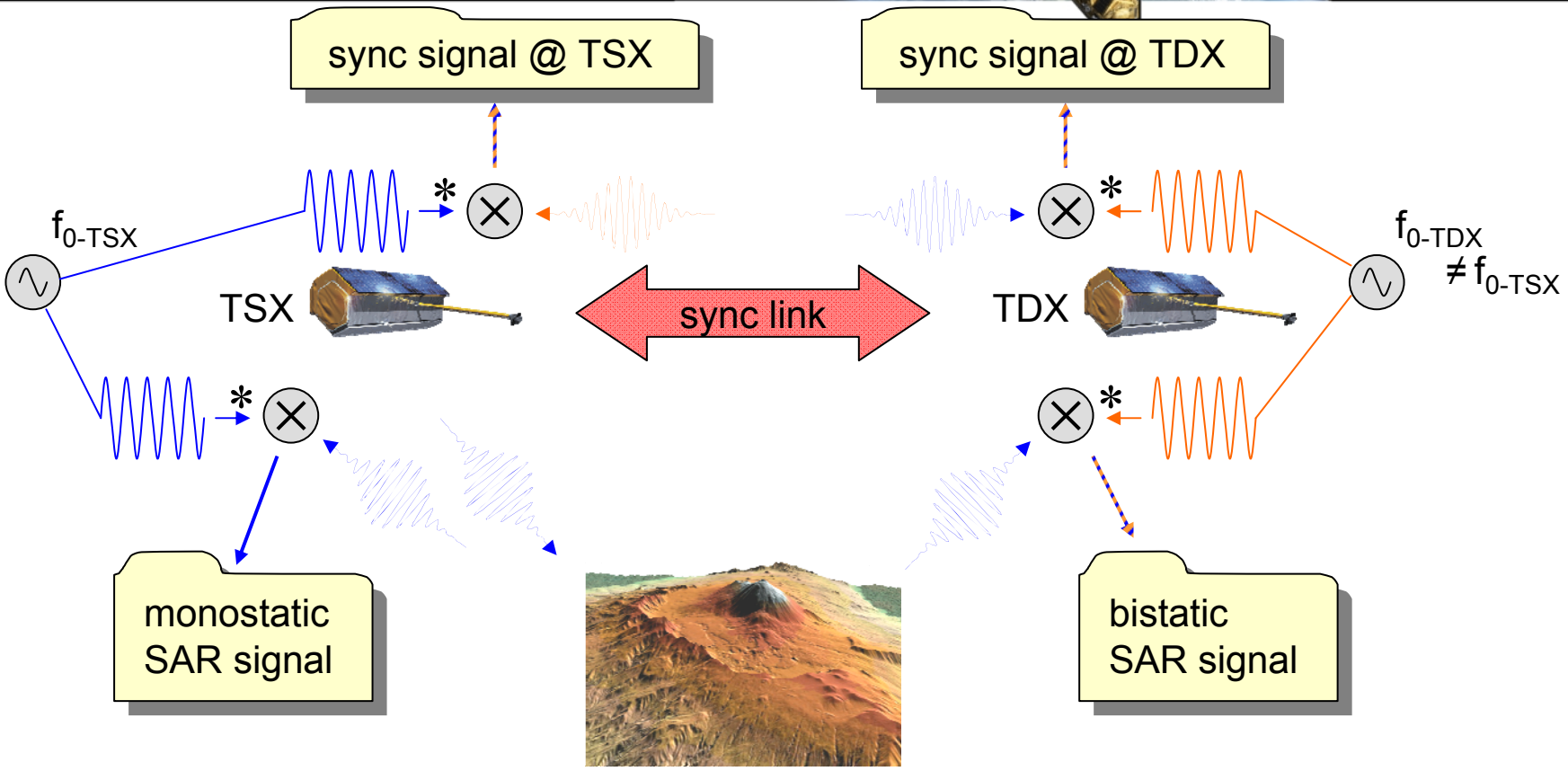
Mt. St. Helens, USA

- challenges:
  - bistatic acquisition geometry
  - combined satellite dependent transmit and receive delays
  - oscillator phase and data take start time synchronisation

Independent Ultra Stable Oscillators in Bistatic Mode



- Problem:
  - carrier frequency and phase of SAR transmitter is not equal to the demodulation frequency of the bistatic SAR receiver and the sampling raster is not adequate.
  - If not compensated, inacceptable image distortions ($\approx 3.7m / s$) and interferometric phase errors ($\approx 2\pi \cdot 120\ rad / s$) occur.

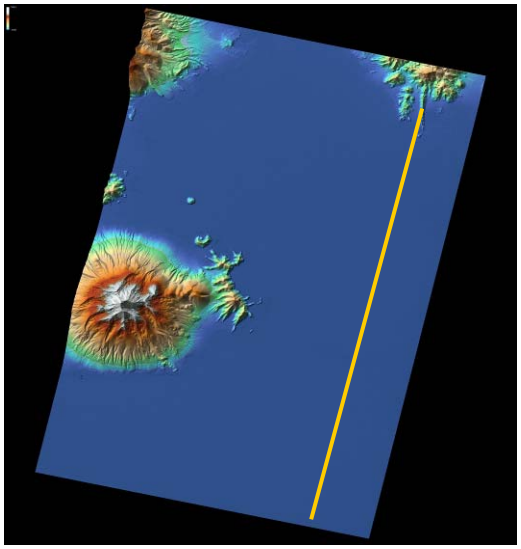


Way Out: Synchronization Pulse Exchange

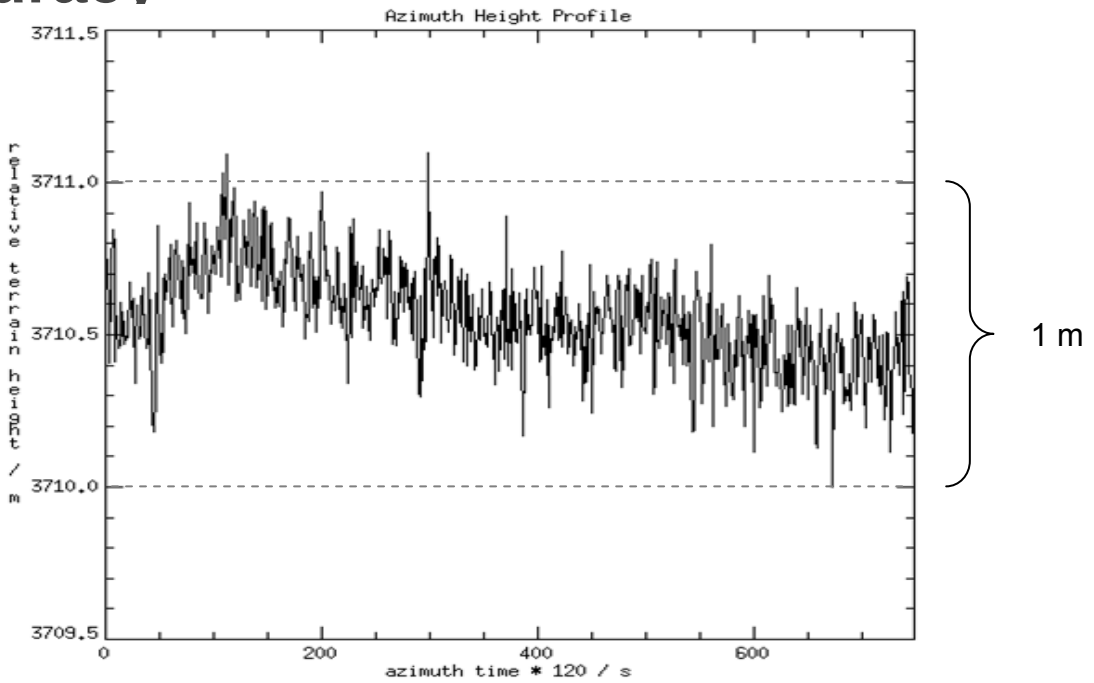
Oscillator and Data Take Start Time Synchronization

- On-ground processing of synchronization pulses, determination of the compensation function including data take start time shift correction
- Challenges:
  - Sync pulse peak locations and phases are affected by unwanted relativistic offsets (cm-level) caused by the motion of the receiving satellite with respect to the transmitter during the sync pulse travel time $\Delta\tau$
  - Measured phase of the sync pulses contains unknown multiples of 2π => Compensation phase is ambiguous by π
- Application of the compensation function during SAR processing

Bistatic Synchronization Accuracy Contribution to Relative Height Accuracy

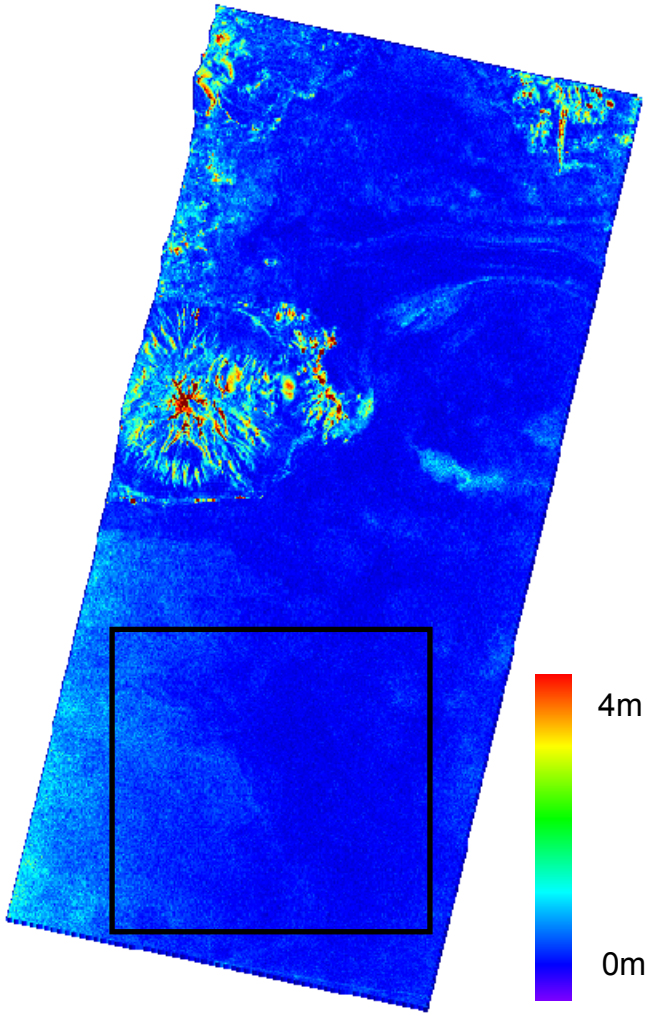


Test Site: Salar de Uyuni, Bolivia

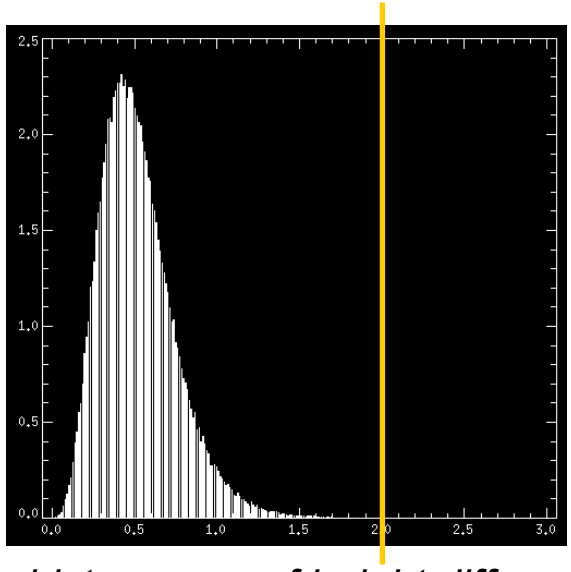


- if correction with fixed frequency offset only => relative height errors in range of +/- 10 m for phase-to-height conversion factor 39 m / 360º
- check of azimuth height profile on flat salt lake area => maximum variation of 30 cm along 40 km
- thus: perfect synchronization, no indication of residual phase errors

Test Site Salar de Uyuni: Difference of 2 bistatic raw DEMs



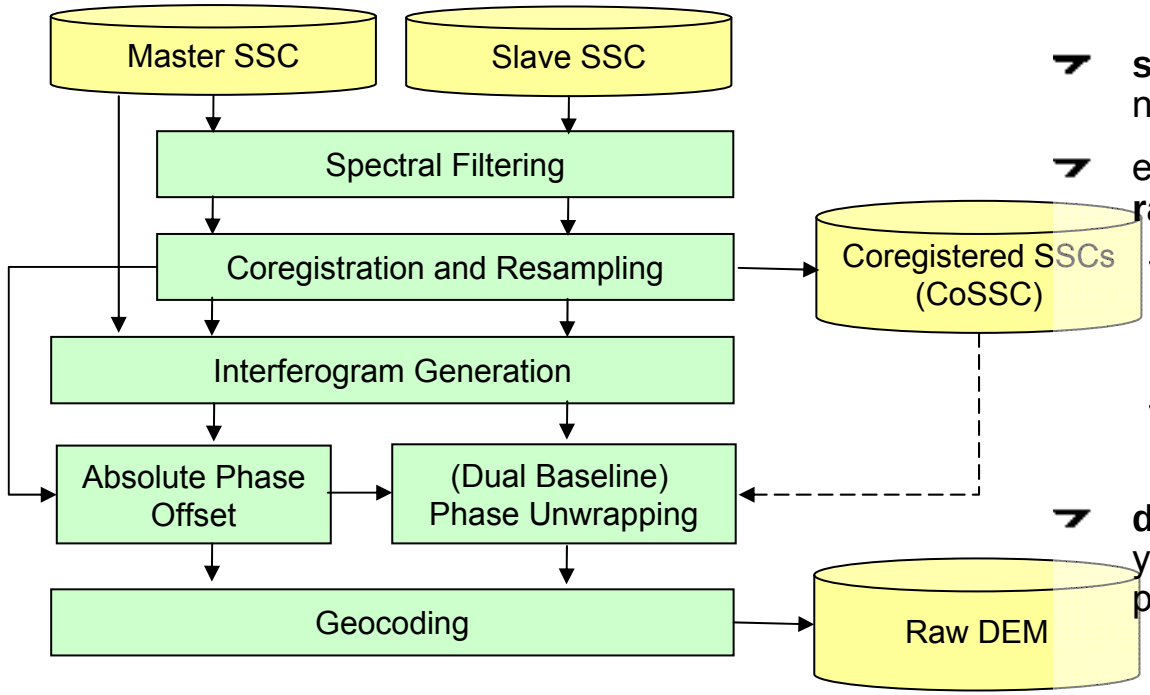
2m-requirement (90%)



histogramm of height differences

- Raw DEMs are free of of time varying height errors potentially caused by oscillator offsets and drifts or other system errors

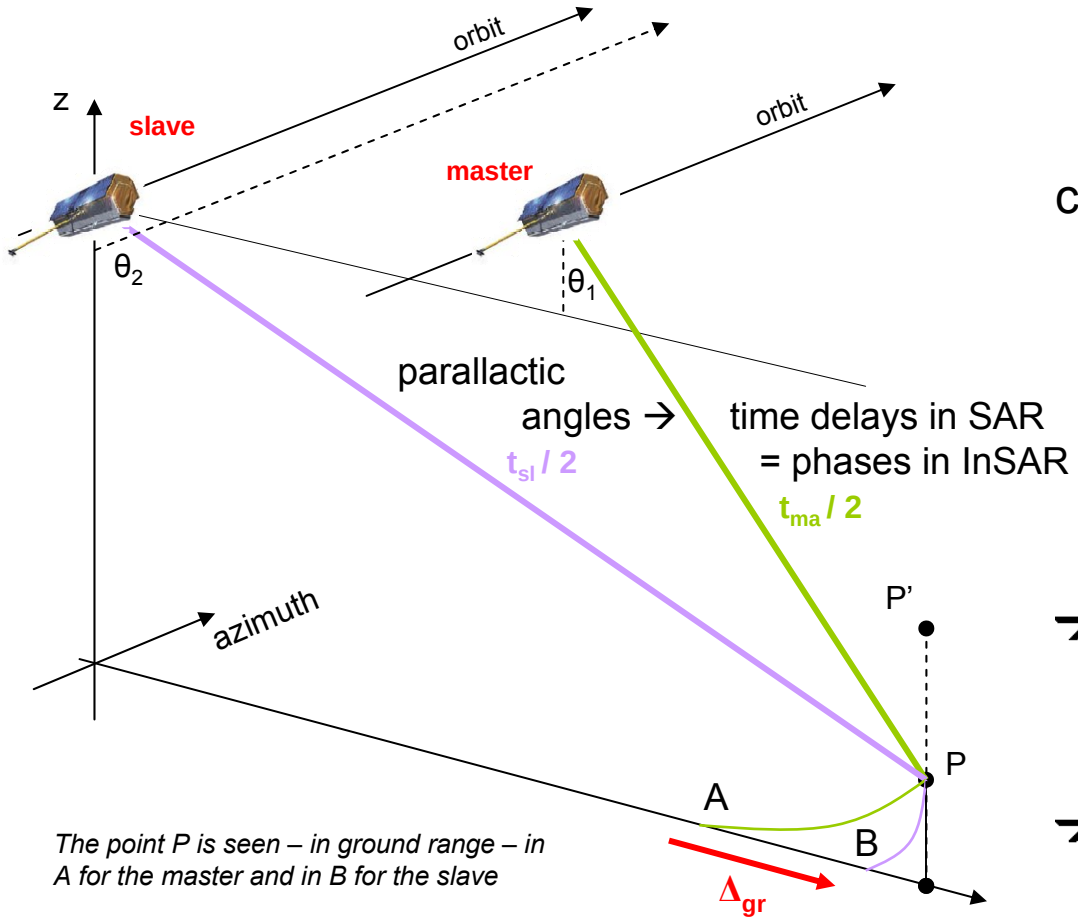
ITP Interferometric Processing Sequence



- **signal based high-res. coregistration** no reference DEM required
- essential “byproduct”: **radargrammetric** shifts used for
  - **absolute phase offset** determination = absolute height “pre-” calibration
  - fully automated phase unwrapping **quality control**
- **dual baseline phase unwrapping** in 2nd year using both coverages to unwrap the problematic (large baseline) data

Coregistered Single-Look Slant-range Complex (CoSSC) products are intermediate products for dual baseline phase unwrapping & experimental user products

Absolute Radargrammetric Heights



Coregistration range shift $\Delta = \Delta(h)$

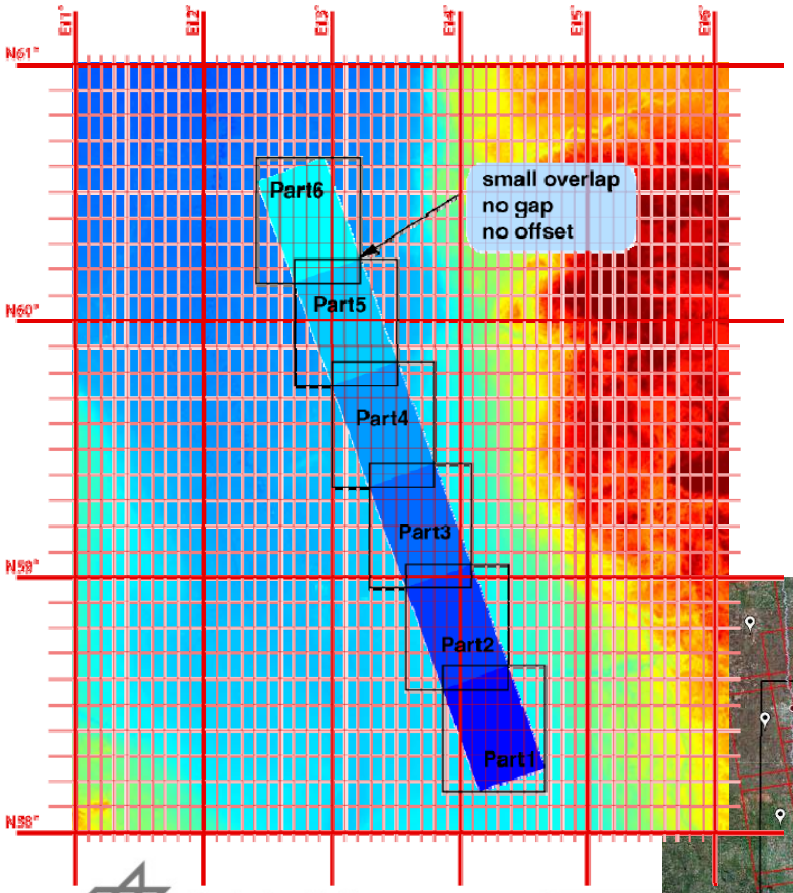
coregistration => radargrammetric shift **if**

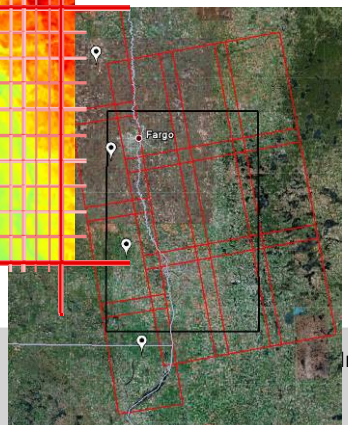
- **all** instrument delays are well calibrated
- orbits / baselines are known

- independant from reference data (specifically in polar regions)
- achievement of consistent estimates for all scenes of data take

Absolute Phase Offset, DEM Processing & Calibration

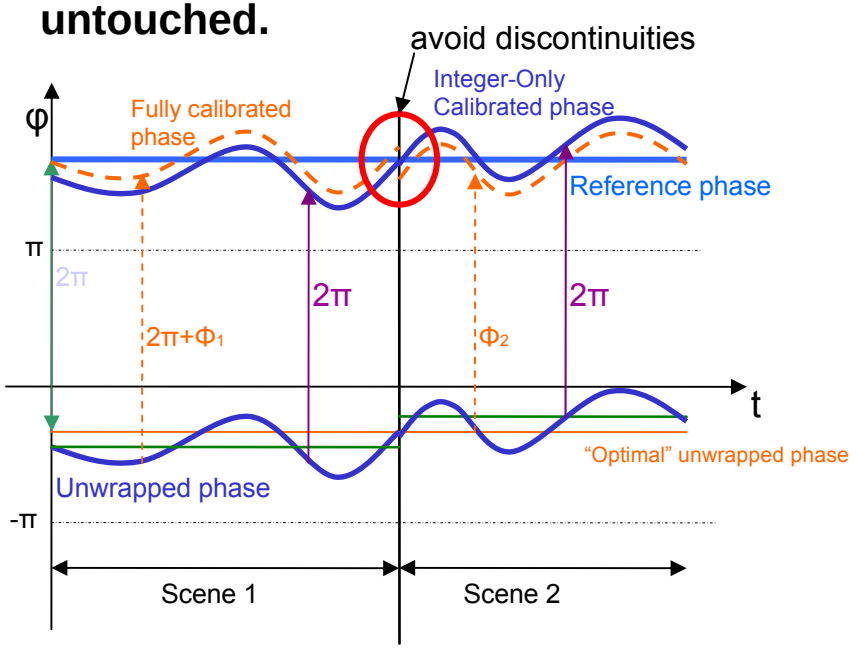
Long data takes split in ***independently processed*** **scenes**: **DEM continuity** is required to apply only data take based small residual **DEM calibration** parameters (tilts, trends, …) in MCP





ITP pre-calibrates each individual scene without *any* tie-pointing!

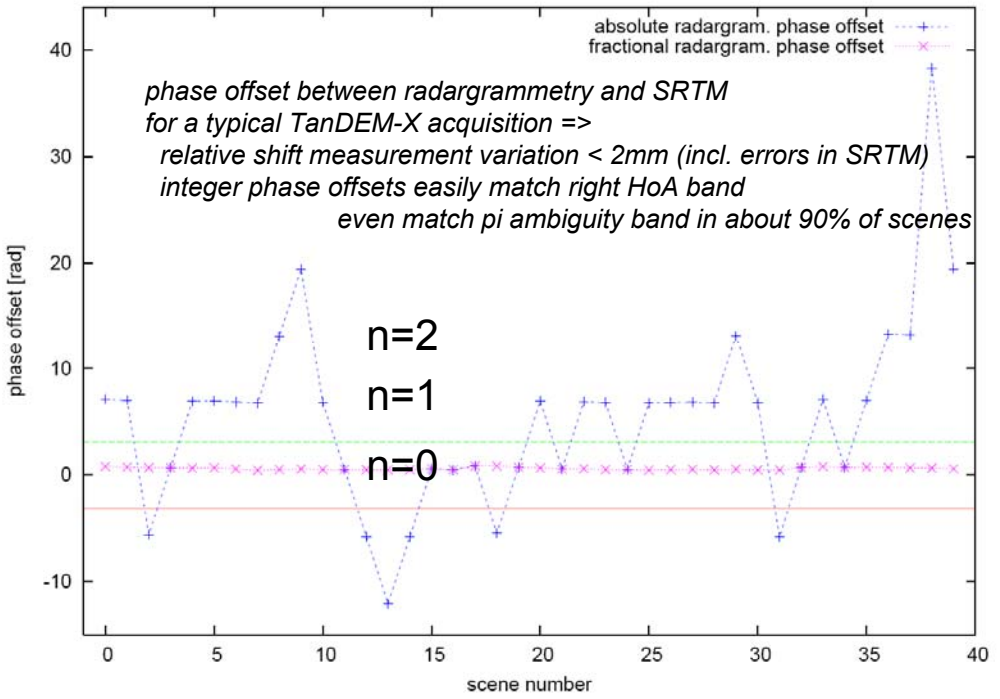
Only integer offset corrections applied, fractional phases untouched.

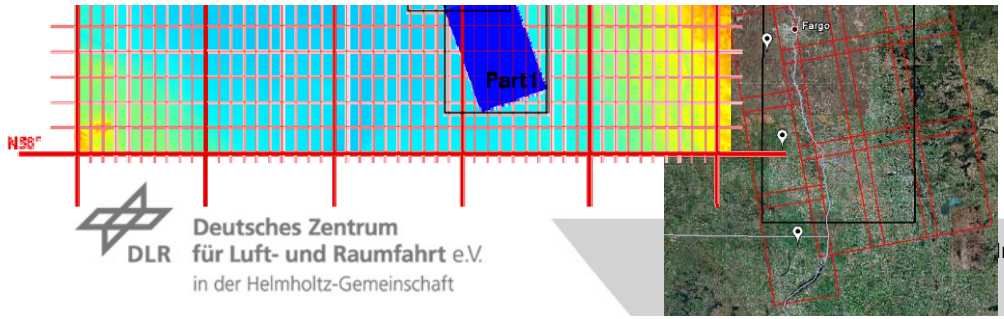


scenes = 50x30 km @ 3m res.

Absolute Phase Offset, DEM Processing & Calibration

Long data takes split in ***independently processed*** **scenes**: **DEM continuity** is required to apply only data take based small residual **DEM calibration** parameters (tilts, trends, …) in MCP





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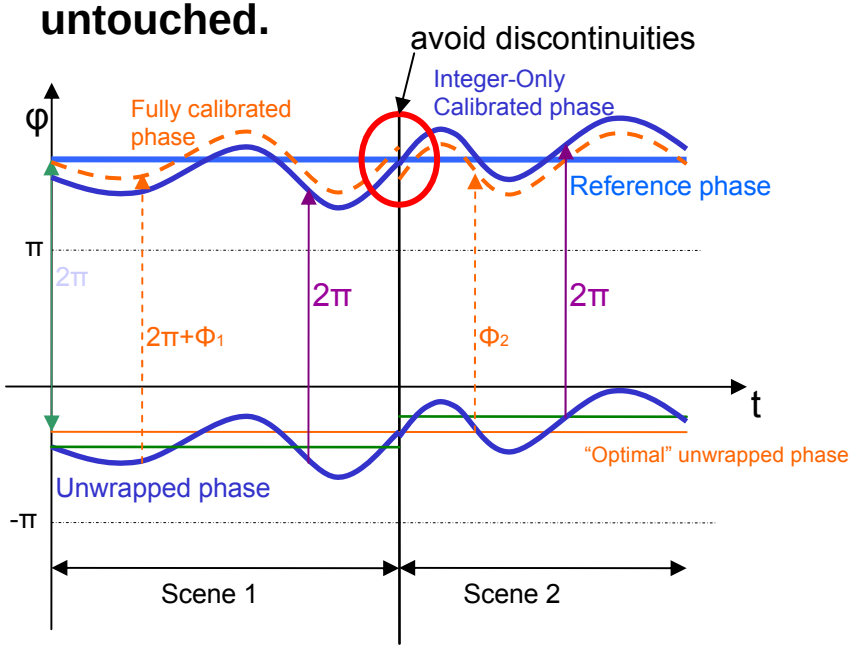
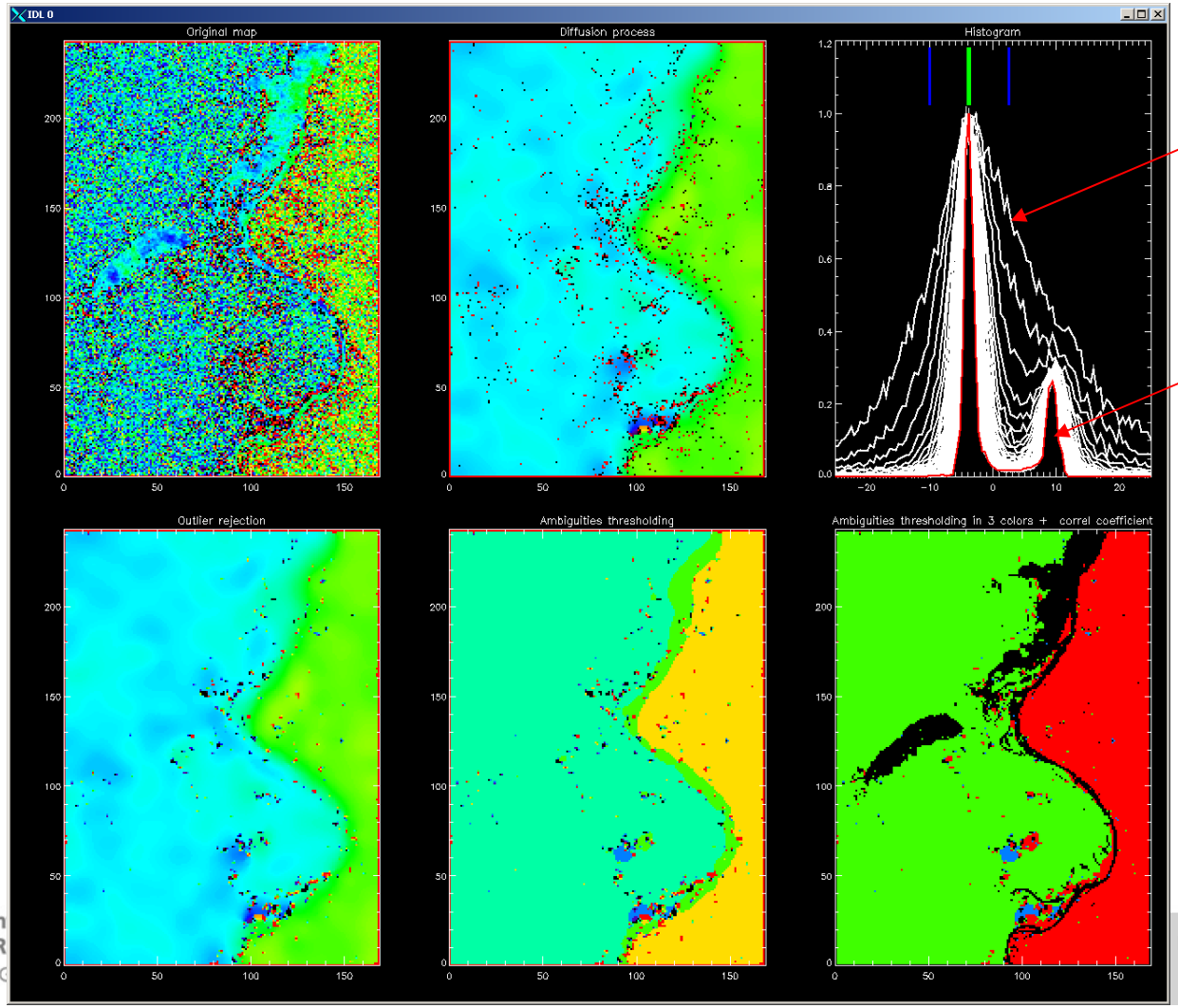


scenes = 50x30 km @ 3m res.

Radargrammetry for Phase Unwrapping Quality Control

A filtering step is implemented for the “histogram shrinking” step to robustly detect **only one** distinct **phase offset ←→ outliers are incoherent and / or unwrapping errors**

color coded difference (in cycles) between radargrammetric and unwrapped phase for each patch



original histogram

final histogram

Ex: two clear phase unwrapping regions are detected after an **Anisotropic Diffusion (Perona & Malik) filter**

Feed Back Loops for Bistatic Calibration

Complex feed back loops were implemented in the TanDEM-X ground segment for the challenging bistatic calibration of the overall system.

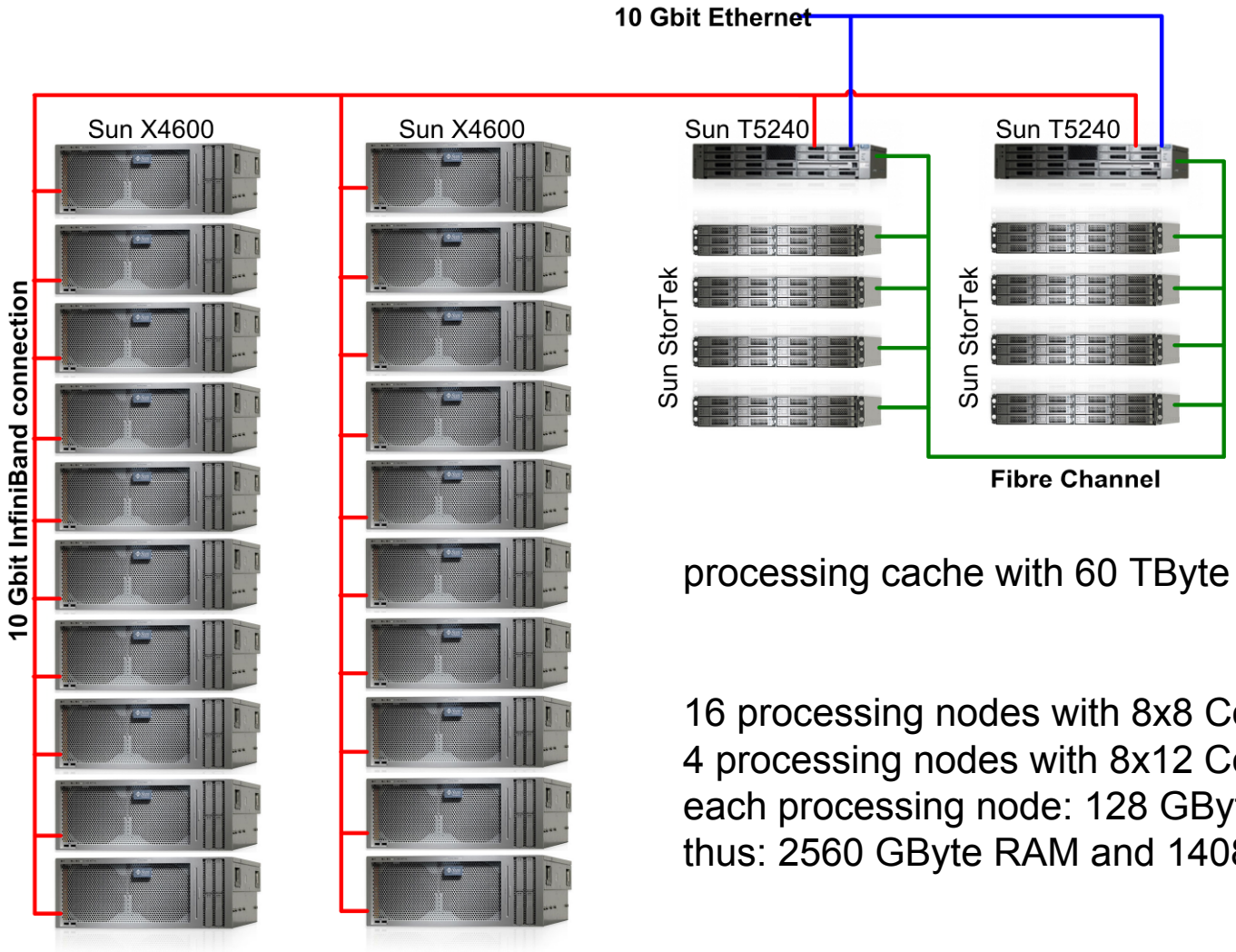
ITP performed the analysis for

- radargrammetric phase calibration: calibration/determination of all bistatic delays, e.g. RX gain, sync horn
- sync errors in interferometric phase
- sync link signal quality (gain optimization) and oszillator stability monitoring
- acquisition quality assessment (beam illumination, common coverage)
- interferometric quality parameters (coherence, phase unwrapping error detection) for optimization of acquisition strategy

ITP Throughput and Quality Control

- designed for 600 Raw DEM scenes per day
  (about 150 % in terms of daily expected TanDEM-X acquisitions)
- able to generate 1300 Raw DEM scenes per day
- no operator interaction, automated system inherent quality control:
  - coherence
  - phase unwrapping ratio (residual density, branch cuts), phase unwrapping statistics
  - …
- philosophy: annotate suitable quality measures, flag deviations, but do not yet make final quality decisions
- however: interactive quality control done at DEM mosaicking and calibration which may initiate reprocessings at ITP
- ITP Production and Quality Data Base gathers comprehensive ITP info (annotation and parameter files, quicklooks, maps, parameter plots, log files,…) and stores a large set of parameters to support data base queries

Processing System ITP Hardware Environment



processing cache with 60 TByte

16 processing nodes with 8x8 Core Opteron CPU
4 processing nodes with 8x12 Core Opteron CPU
each processing node: 128 GByte RAM
thus: 2560 GByte RAM and 1408 CPUs in total

You are here : **Home : qa_yearly_processing**

back

TanDEM-X Production Database / Daily Production

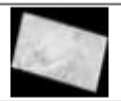
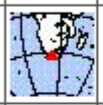
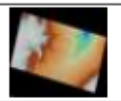
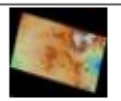
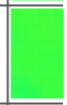
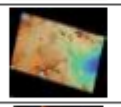
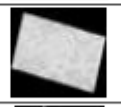
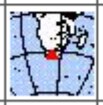
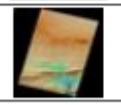
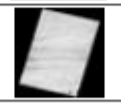
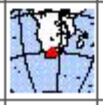
RDEMGEN production on 28.10.2011 past 11:36:23

Hour 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23

	Id	Generation Time	Acquisition	Master Slave	TDX Orbit TSX Orbit	Scene	Scene Start Master Scene Start Slave	Map	DEM	Coherence	Radar-grammetry	Phase
>	231881	11 36:23	1022901	TSX-1 TDX-1	22332 22332	27	2011-06-25T01:06:44.564496 2011-06-25T01:06:44.564496					
>	231882	11 37:30	1022				1.564429 1.564429					
>	231883	11 37:45	1022				8.564362 8.564362					
>	231884	11 39:02	1022901	TSX-1 TDX-1	22332 22332	30	2011-06-25T01:07:05.564295 2011-06-25T01:07:05.564295					
>	231885	11:39:32	1022901	TSX-1 TDX-1	22332 22332	32	2011-06-25T01:07:19.564161 2011-06-25T01:07:19.564161					
>	231886	11:42:18	1022901	TSX-1 TDX-1	22332 22332	31	2011-06-25T01:07:12.564228 2011-06-25T01:07:12.564228					
>	231887	11:42:45	1022901	TSX-1 TDX-1	22332 22332	34	2011-06-25T01:07:33.564027 2011-06-25T01:07:33.564027					
>	231888	11:44:05	1022901	TSX-1 TDX-1	22332 22332	33	2011-06-25T01:07:26.564094 2011-06-25T01:07:26.564094					
>	231889	11:45:56	1022901	TSX-1 TDX-1	22332 22332	35	2011-06-25T01:07:40.563960 2011-06-25T01:07:40.563960					
>	231890	11:47:13	1024074	TDX-1 TSX-1	224 22480	3	2011-07-04T19:45:41.734113					
>	231892	11:48:31	1022901	TSX-1 TDX-1	22332 22332	36	2011-06-25T01:07:47.563893 2011-06-25T01:07:47.563893					

see generation time stamps for single scene Raw DEM generation frequency

blue=water (Globecover)

>	231928	12:21:11	1010461	TSX-1 TDX-1	19980 19980	23	2011-01-21T03:46:01.291428 2011-01-21T03:46:01.291428					
>	231929	12:22:55	1010461	TSX-1 TDX-1	19980 19980	33	2011-01-21T03:47:11.292958 2011-01-21T03:47:11.292958					
>	231930	12:23:11	1010461	TSX-1 TDX-1	19980 19980	34	2011-01-21T03:47:18.293111 2011-01-21T03:47:18.293111					
>	231931	12:23:32	1010461	TSX-1 TDX-1	19980 19980	31	2011-01-21T03:46:57.292652 2011-01-21T03:46:57.292652					
>	231932	12:24:06	1010461	TSX-1 TDX-1	19980 19980	32	2011-01-21T03:47:04.292805 2011-01-21T03:47:04.292805					
>	231933	12:24:30	1010461	TSX-1 TDX-1	19980 19980	35	2011-01-21T03:47:25.293264 2011-01-21T03:47:25.293264					
>	231935	12:24:38	1010461	TSX-1 TDX-1	19980 19980	29	2011-01-21T03:46:43.292346 2011-01-21T03:46:43.292346					
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>	231937	12:33:54	1012222	TDX-1 TSX-1	20557 20557	6	2011-02-28T03:16:43.727836 2011-02-28T03:16:43.727836					
>	231938	12:34:40	1012222	TDX-1 TSX-1	20557 20557	7	2011-02-28T03:16:50.727945 2011-02-28T03:16:50.727945					
>	231939	12:36:13	1012222	TDX-1 TSX-1	20557 20557		18 18					
>	231940	12:36:54	1012222	TDX-1 TSX-1	20557 20557	8	54 2011-02-28T03:16:57.728054					
>	231941	12:37:30	1012222	TDX-1 TSX-1	20557 20557	9	2011-02-28T03:17:04.728163 2011-02-28T03:17:04.728163					
>	231942	12:38:03	1012222	TDX-1 TSX-1	20557 20557	11	2011-02-28T03:17:18.728381 2011-02-28T03:17:18.728381					

blue=water (Globecover)
black=problematic region

TDM-1 - RDEMGEN QA - tdm0_w147d73n65d26_20557_20110228T031643_006_ITP

Processing Run Id: 231937, Acquisition Item Id: 1012222, Application: usedForGlobalDEM
TAP Take Id: TAP_0101.211_G_NA_USA_tanDEM_a1_040R_002318
Baseline Product: TDM1_GFZ__BSL_CALB_20110227T234945_20110228T120945_20110819T201245.xml

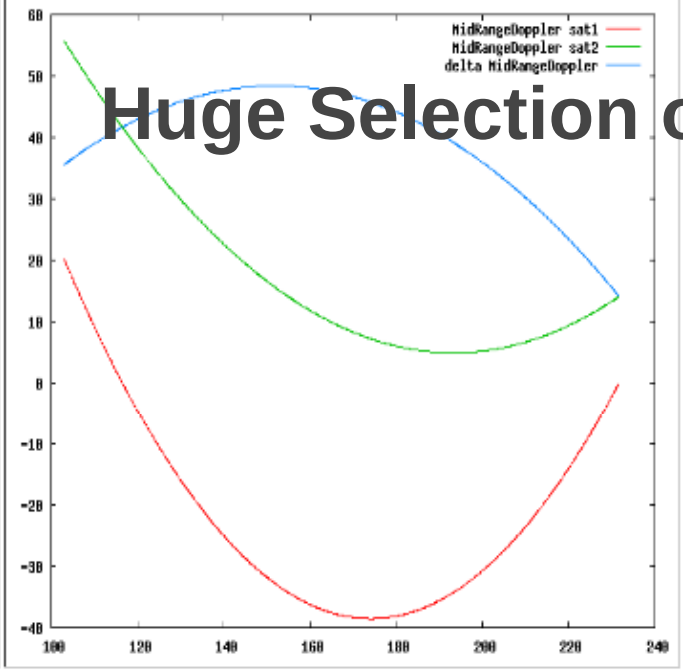
	Master Satellite	Slave Satellite
DT-Times	2011-02-28T03:16:08.910765 2011-02-28T03:18:21.094723	2011-02-28T03:16:08.910765 2011-02-28T03:18:21.094723
SatID	**TDX-1**	**TSX-1**
Orbit	20557 A	20557 A
Imaging Mode	SM (**bistaticActive**)	SM (**bistaticPassive**)
Polarisation	S (HH)	S (HH)
Scene Index 6		
Scene Times	2011-02-28T03:16:43.727836 2011-02-28T03:16:51.727774	2011-02-28T03:16:43.727836 2011-02-28T03:16:51.727774
Incidence Angle	36.988 .. 39.962	37.022 .. 39.990

Status	Quality related Parameters				Logging Messages					Consistency	
	Average Coherence	0.755399	Normalized	1.756742		ALARM	EXCEPTION	QA_WARNING	WARNING		
	Effective Baseline	146.31 m	Alongtrack	70.52 m	common	0	0	0	1		
	Height of Ambiguity	43.00 m	Track Distance	304.55 m	master	0	0	0	0	Archive product	not performed
generated on 2011-10-28 at 12:33:54					slave	0	0	0	1	ZIP integrity	?
	show parameter table				InSAR	0	0	0	14		
					total	**0**	**0**	**0**	**16**		

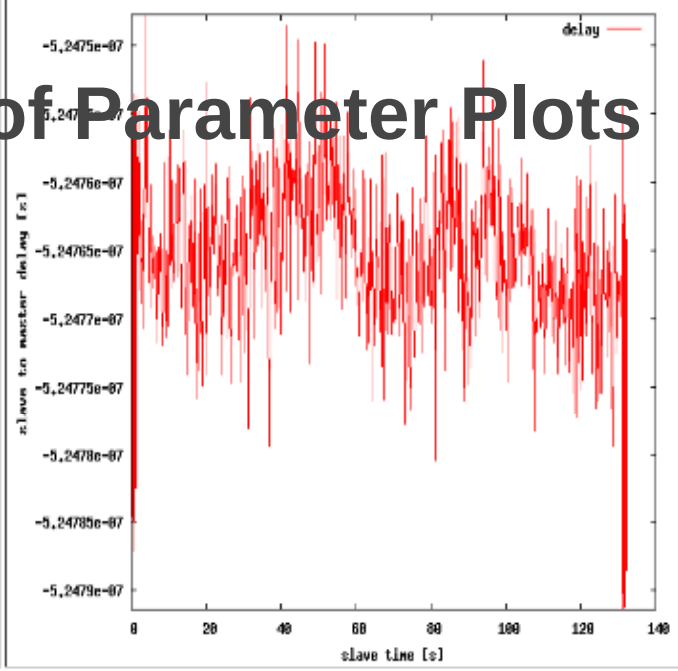
te_phase_offset 14544966673	absolute_phase_offset_radarg -42.2396388210799	absolute_phase_offset_radarg_fractionary_part 0.171815675587447
ition_item_id 22	acquisition_mode SM	acquisition_time 2011-02-28T03:16:43.727836Z
a_receive_configuration_master	antenna_receive_configuration_slave SRA	applied_to usedForGlobalDEM
slave M_a1_040	center_incidence_angle_master 38.5255328546174	center_incidence_angle_slave 38.5347809360956
on_warnings	cooperative_mode_master bistaticActive	cooperative_mode_slave bistaticPassive
cross_corr_patch_size_az	coreg_cross_corr_patch_size_rg 32	cossc_component_primary TDM1_SAR__COS_BIST_SM_S_SRA_20110228T031643_20110228T031651/TDX1_SAR_
matrix_pixel_unit	datatake_class_master IMAGING	datatake_class_slave IMAGING
osting_class	distance_active_pos 70.5162768552177	distance_tracks 304.545160863899
ions_master	exceptions_slave 0	e_bits_per_pixel_dem 32
max_height_error 4021530151	e_hem_mean_height_error 1.13727986812592	e_hem_min_height_error 0
lsize_northing	e_pixel_unit SE	fringe_frequency_azimuth 0.0034098220262328
range 0.411807157	g_incidence_angle_center 38.5001	g_incidence_angle_far_range 39.9383583068848
ter_orbit_state_vector_vz 2943167034	g_master_orbit_state_vector_x -2730824.57435534	g_master_orbit_state_vector_y -1293957.97441404
e_orbit_state_vector_vx 5076907713	g_slave_orbit_state_vector_vy 5027.36095769994	g_slave_orbit_state_vector_vz 3188.75604700865
conversion_factor 8999484836	hemisphere_ew w	hemisphere_ns n
olution 1	if_sub_azimuth 3	if_sub_range 3
nce_angle_near_range 3	insar_alarms 0	insar_exceptions 0
line_length 2781144667	i_baseline_perpendicular 146.306994440138	i_bl_quality_indicator_max 0.00089
rence_mean 63710212708	i_coherence_min 0.00392156885936856	i_dem_cooperative_mode bistatic
syst_phase_offset_error_radarg_changedby 9265358979	i_height_of_ambiguity 42.9988999484836	i_maneuver_distance_after 98370.572226
layover	i_num_multiple_cut 2264	i_num_negative_residuals 126980
ent_layover	i_percent_multiple_cut 0.000272884441073984	i_percent_negative_residuals 0.174076825380325
apping_type	left_easting	local_height

Huge Selection of Parameter Plots

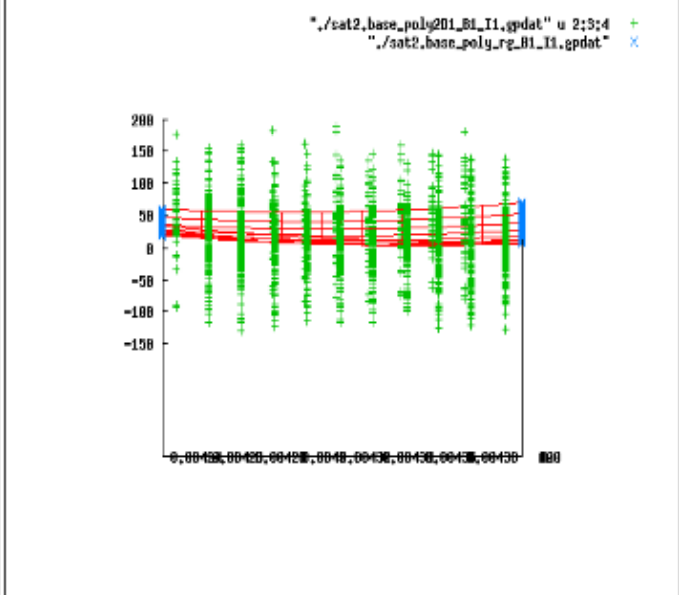
midrange_doppler.png



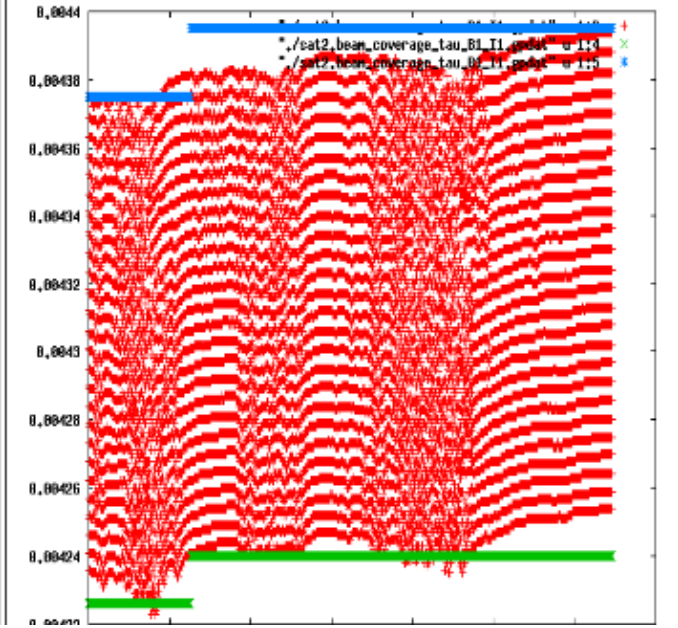
start_time_diff.png



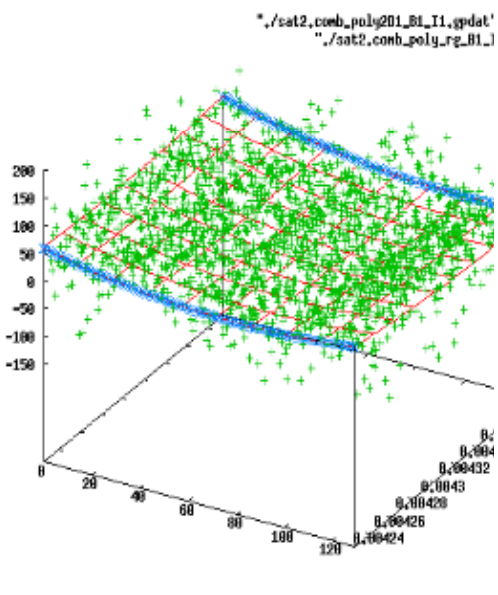
sat2.base_poly2D1_B1_I1.gpdat.view_tau.png



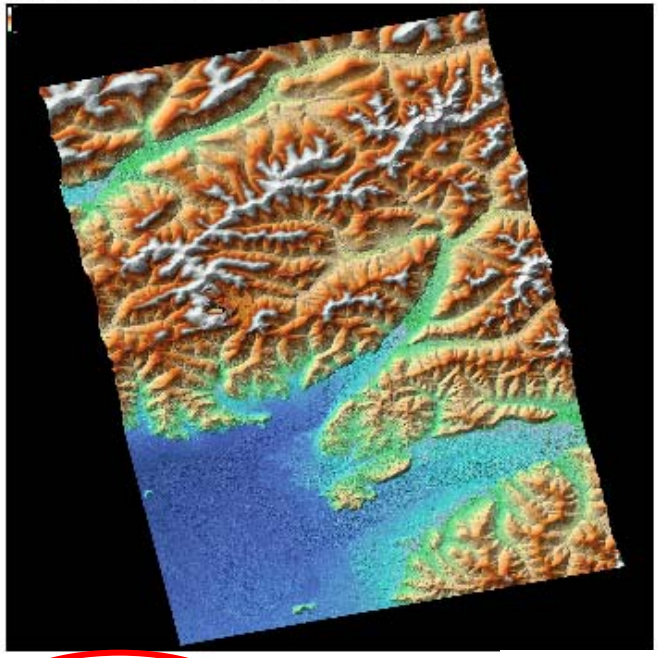
sat2.beam_coverage_tau_B1_I1.gpdat.png



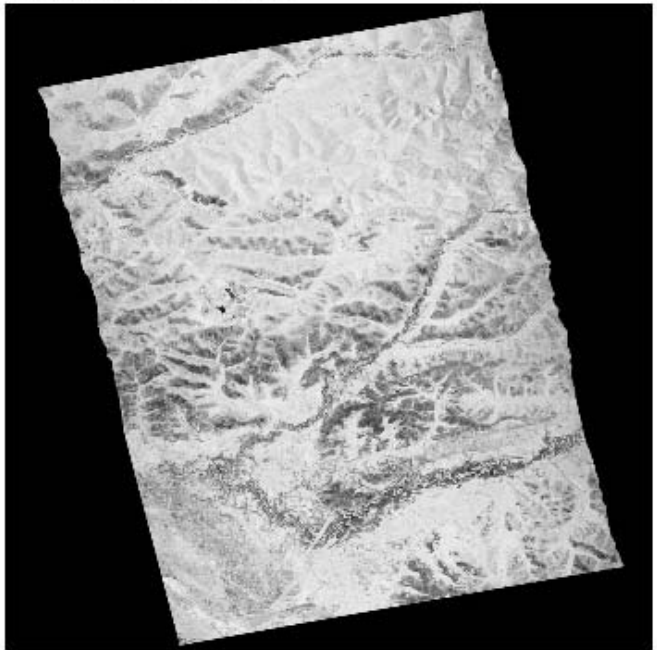
sat2.comb_poly2D1_B1_I1.gpdat.png



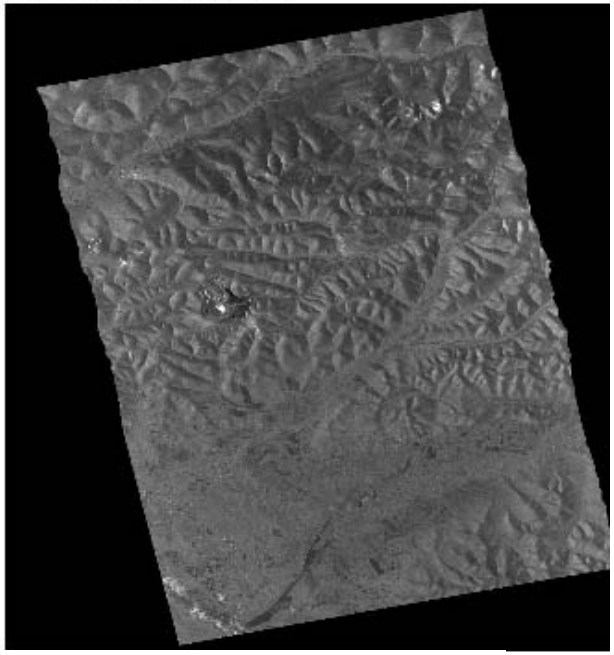
QL_GTC_DEM_hres.jpg



QL_GTC_coherence.jpg

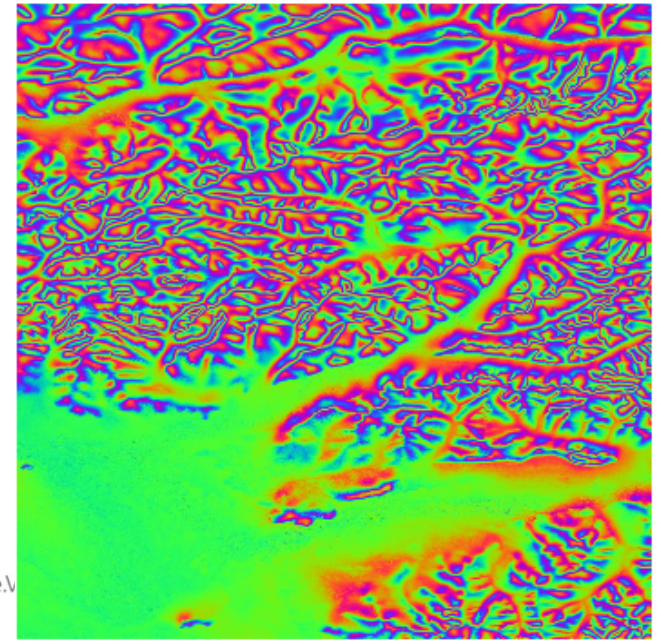


QL_GTC_amplitude.jpg

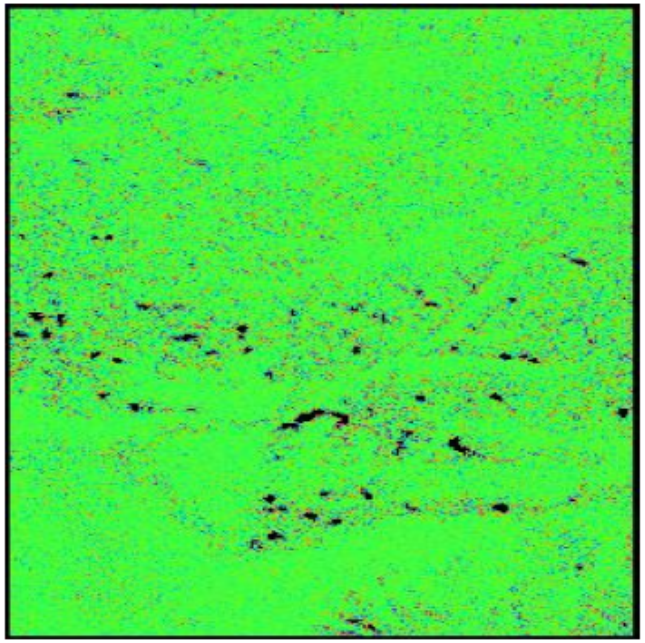


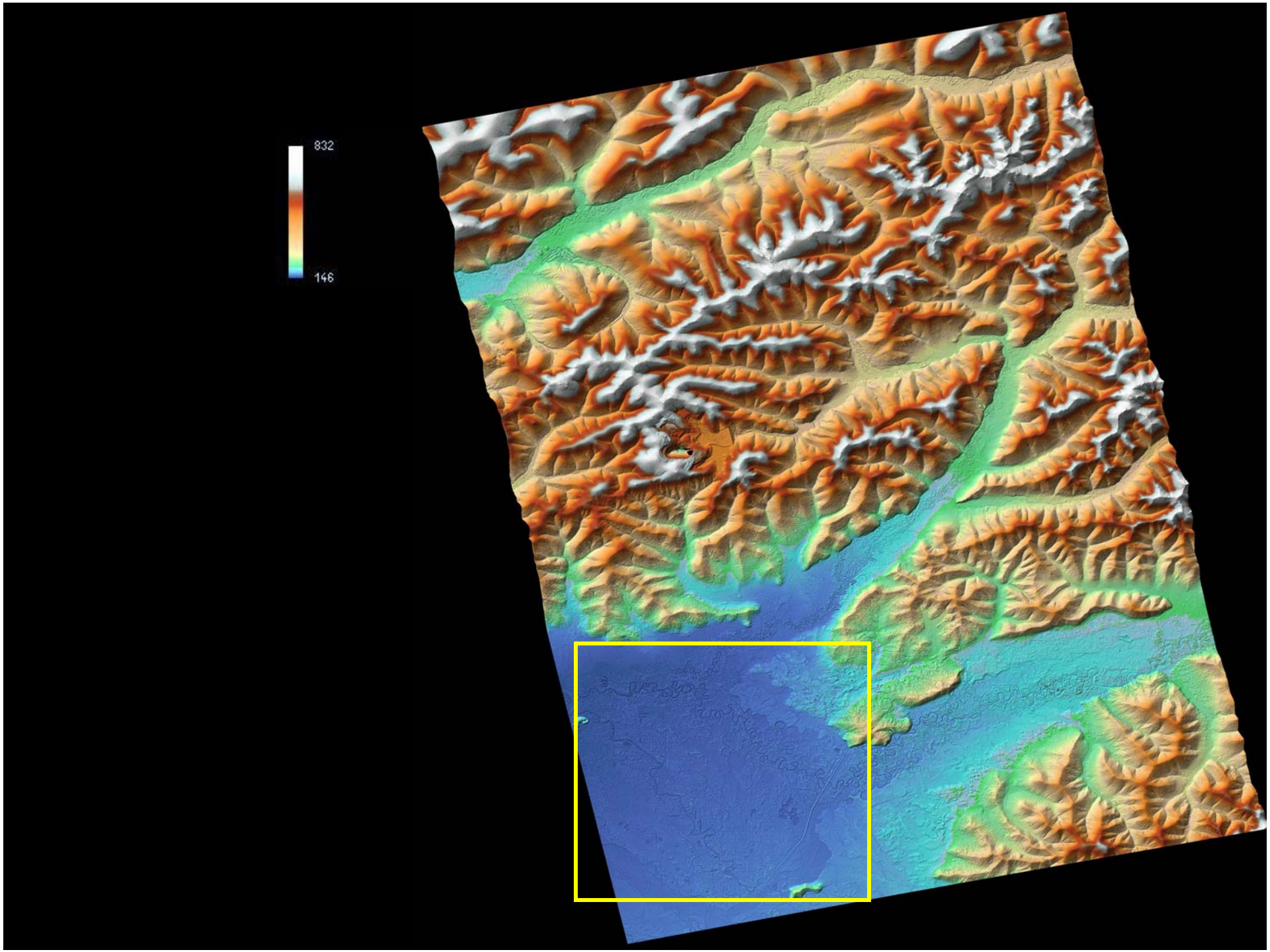
Enlarge Quicklooks

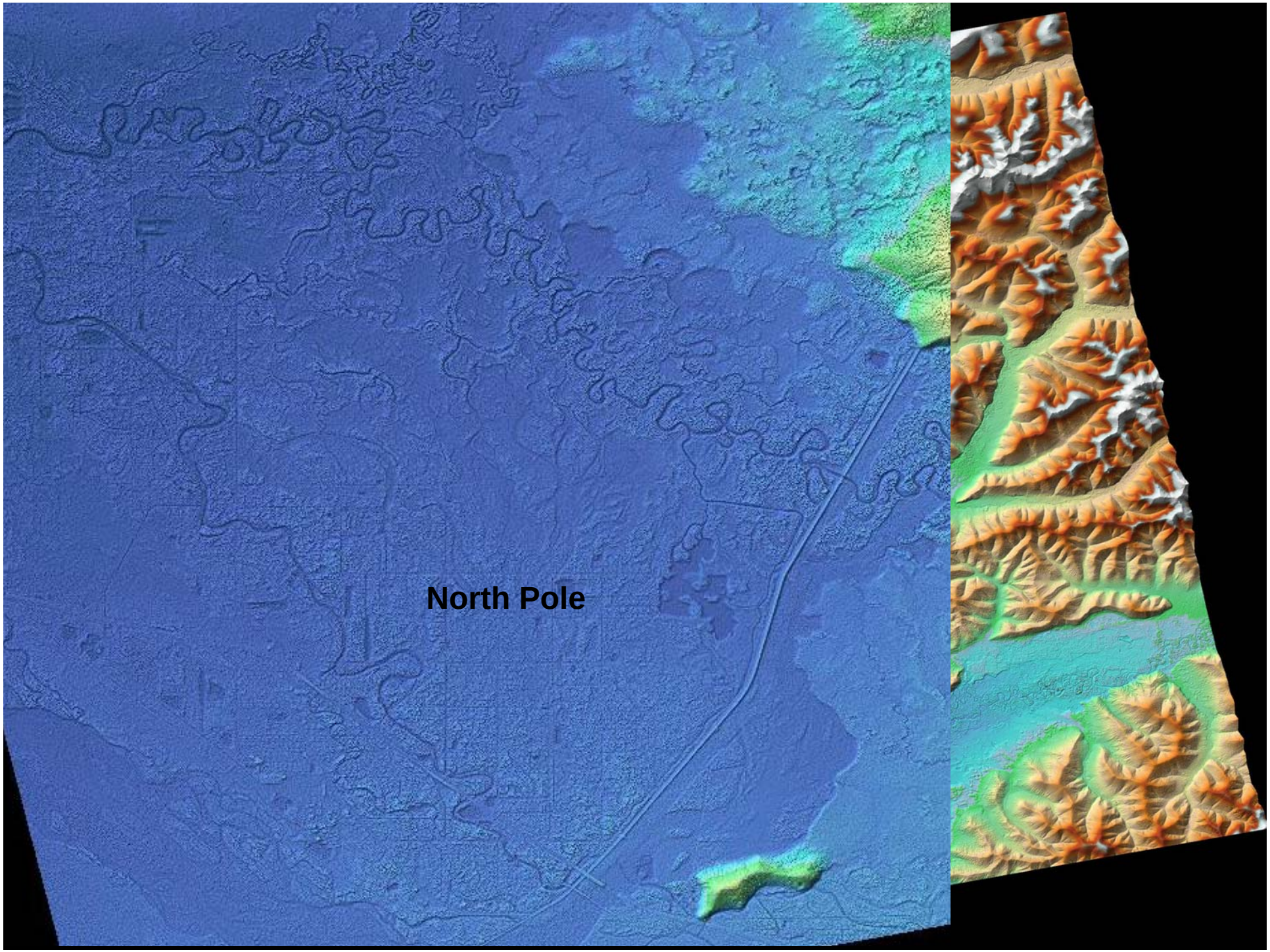
QL_SLT_dinsar_phase.jpg



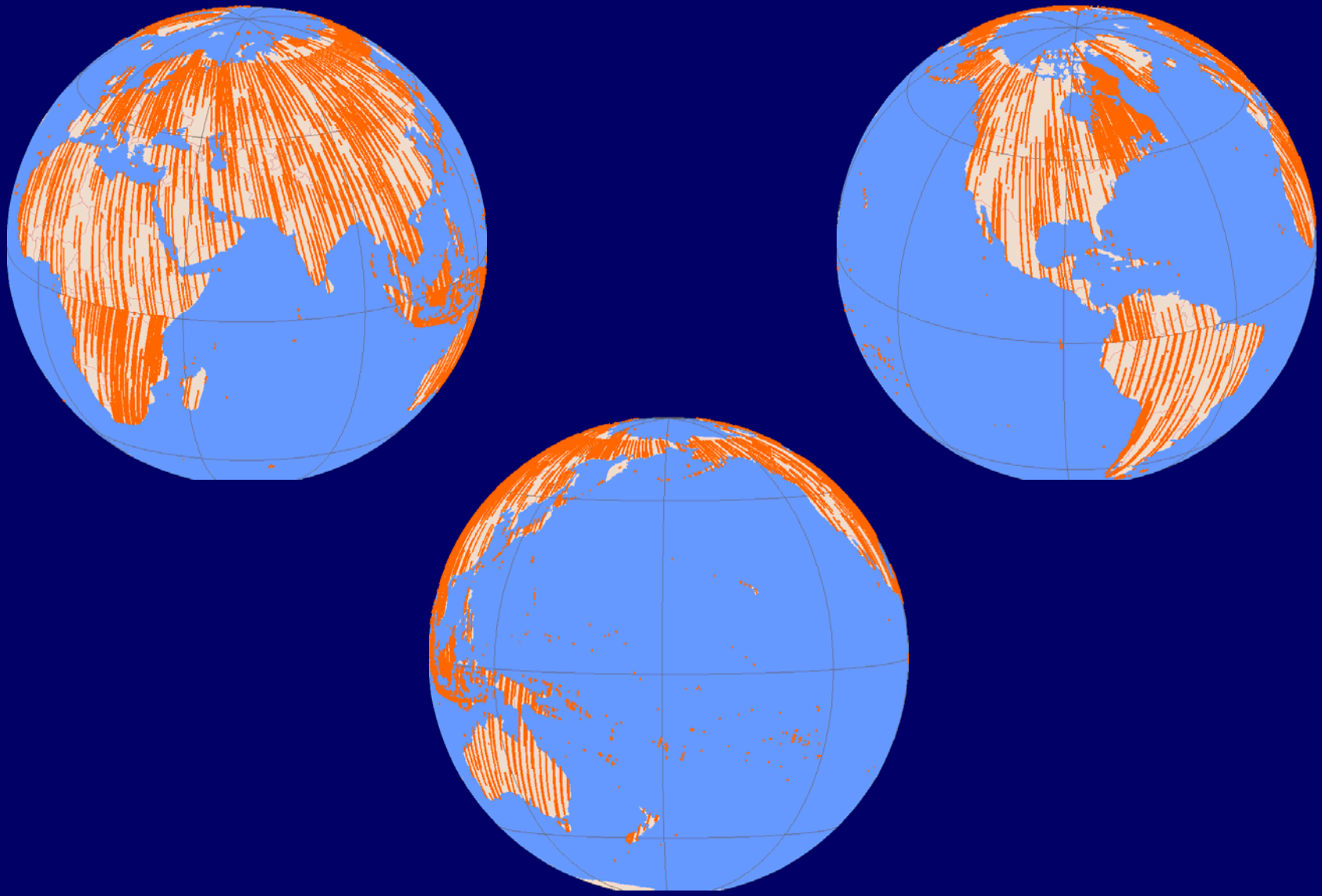
QL_SLT_dinsar_radargr.jpg

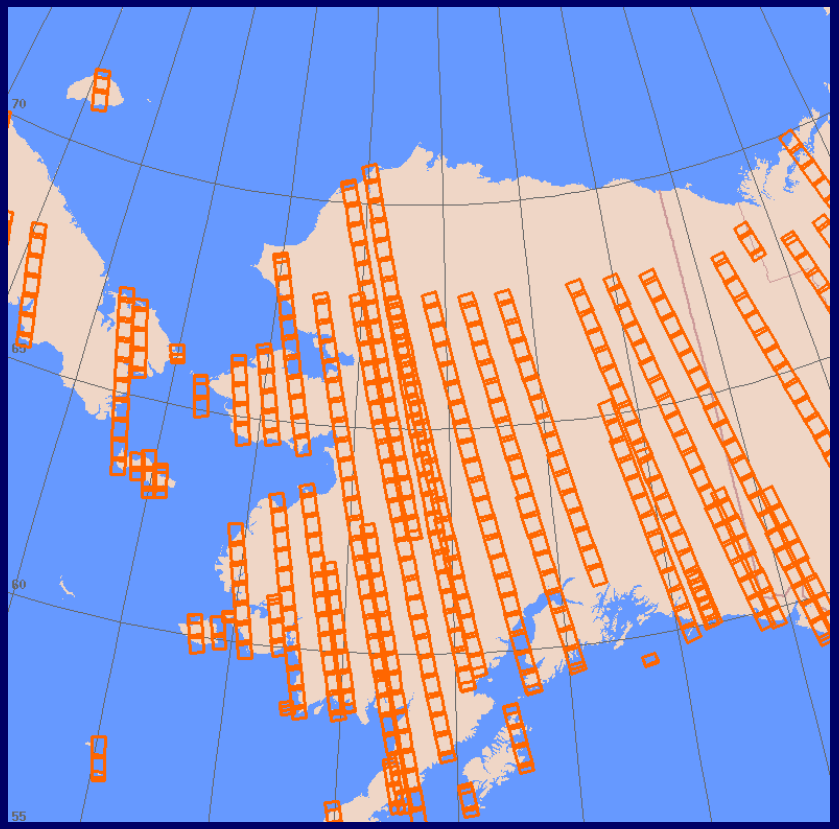



832
146

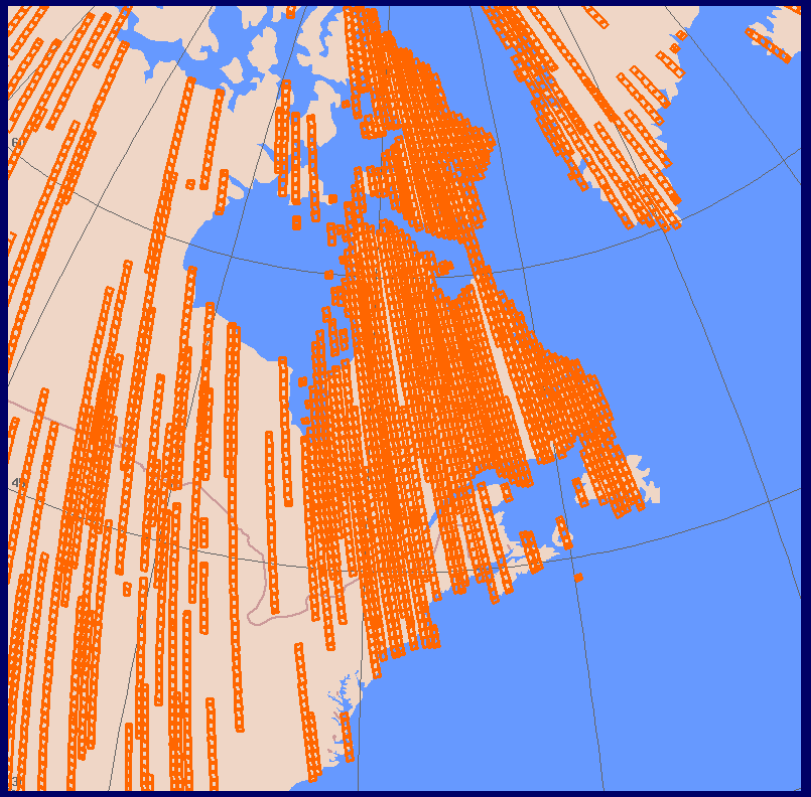

North Pole

Data Processed between Aug 23 and Oct 26

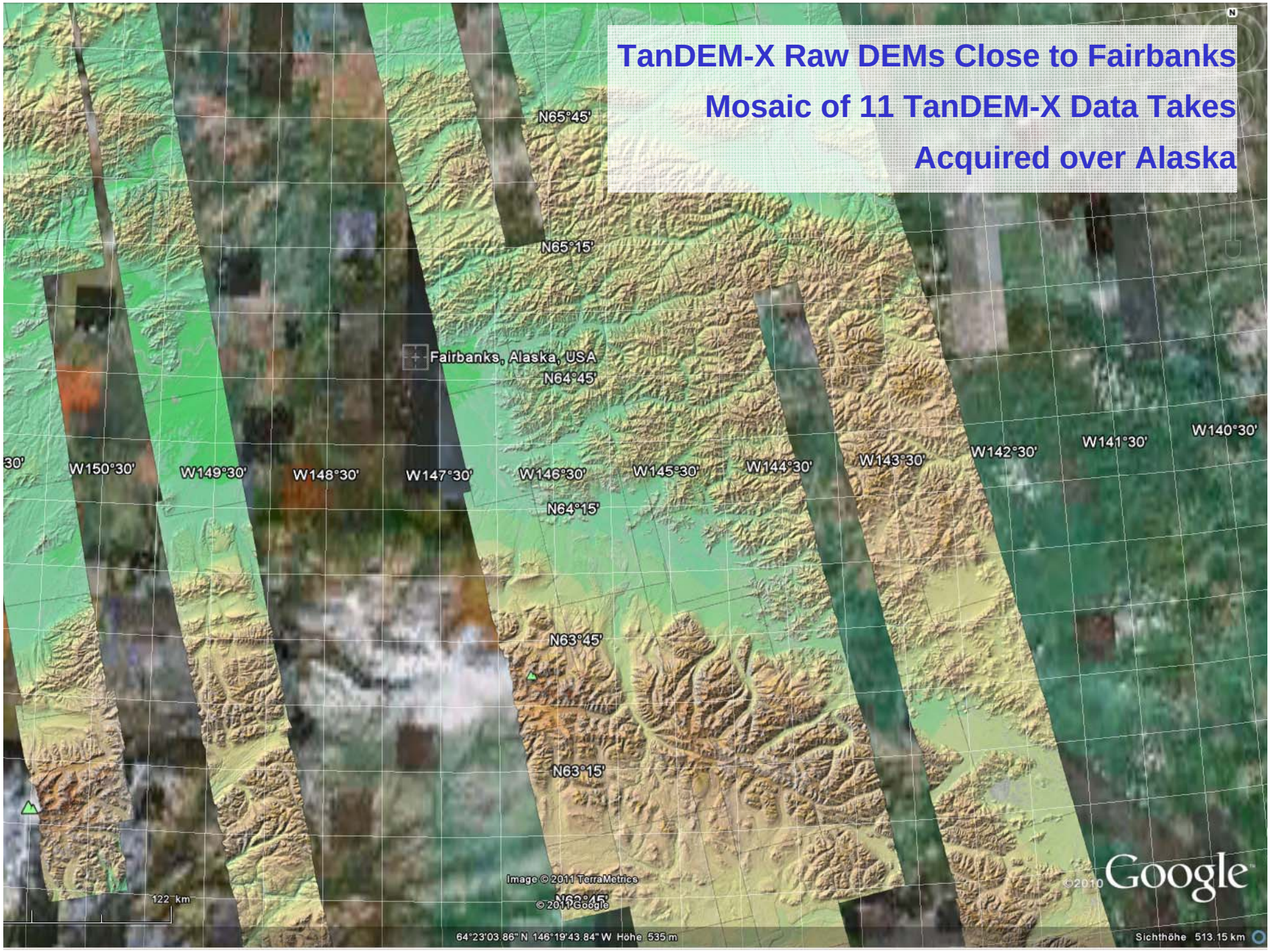


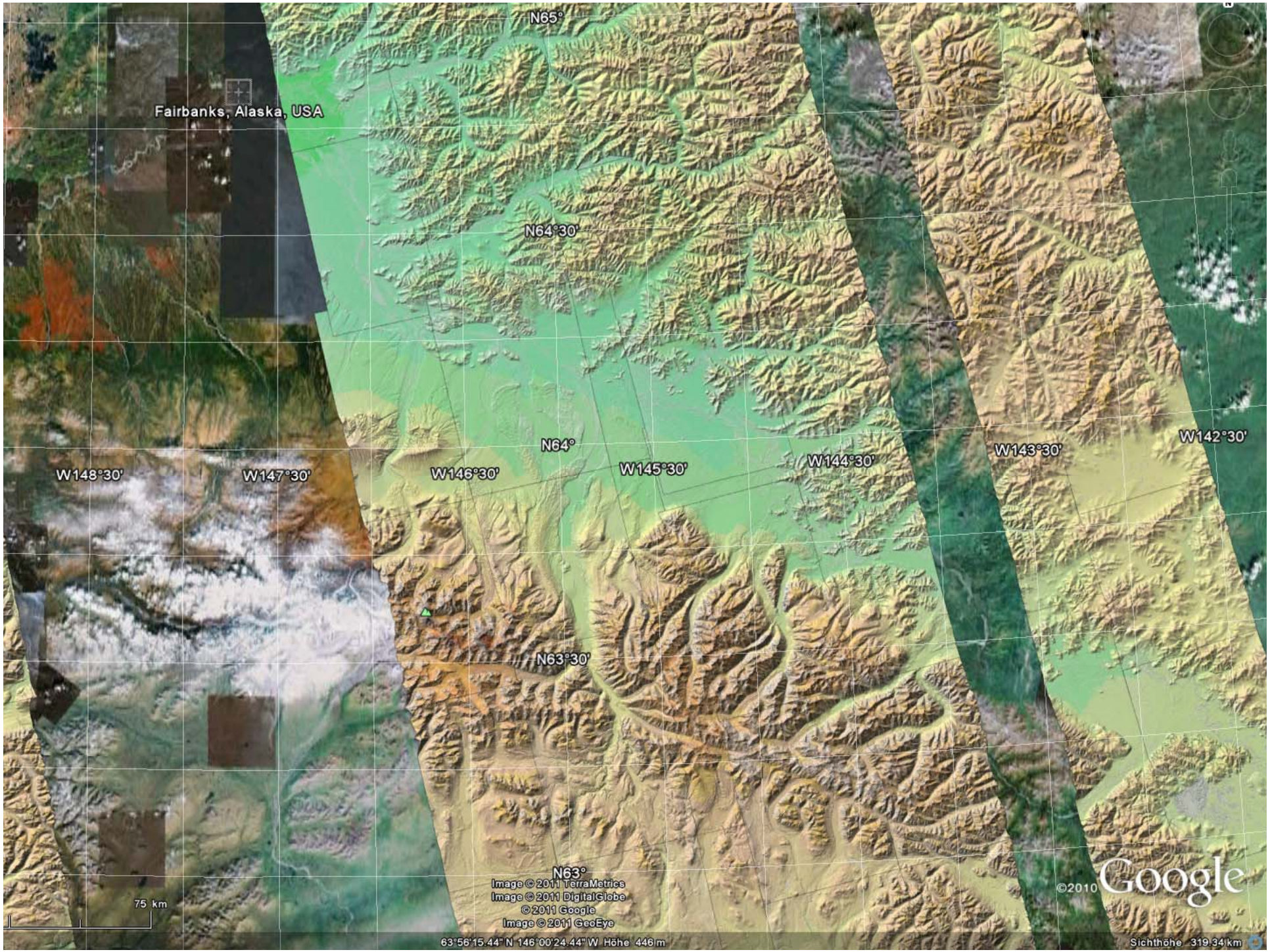


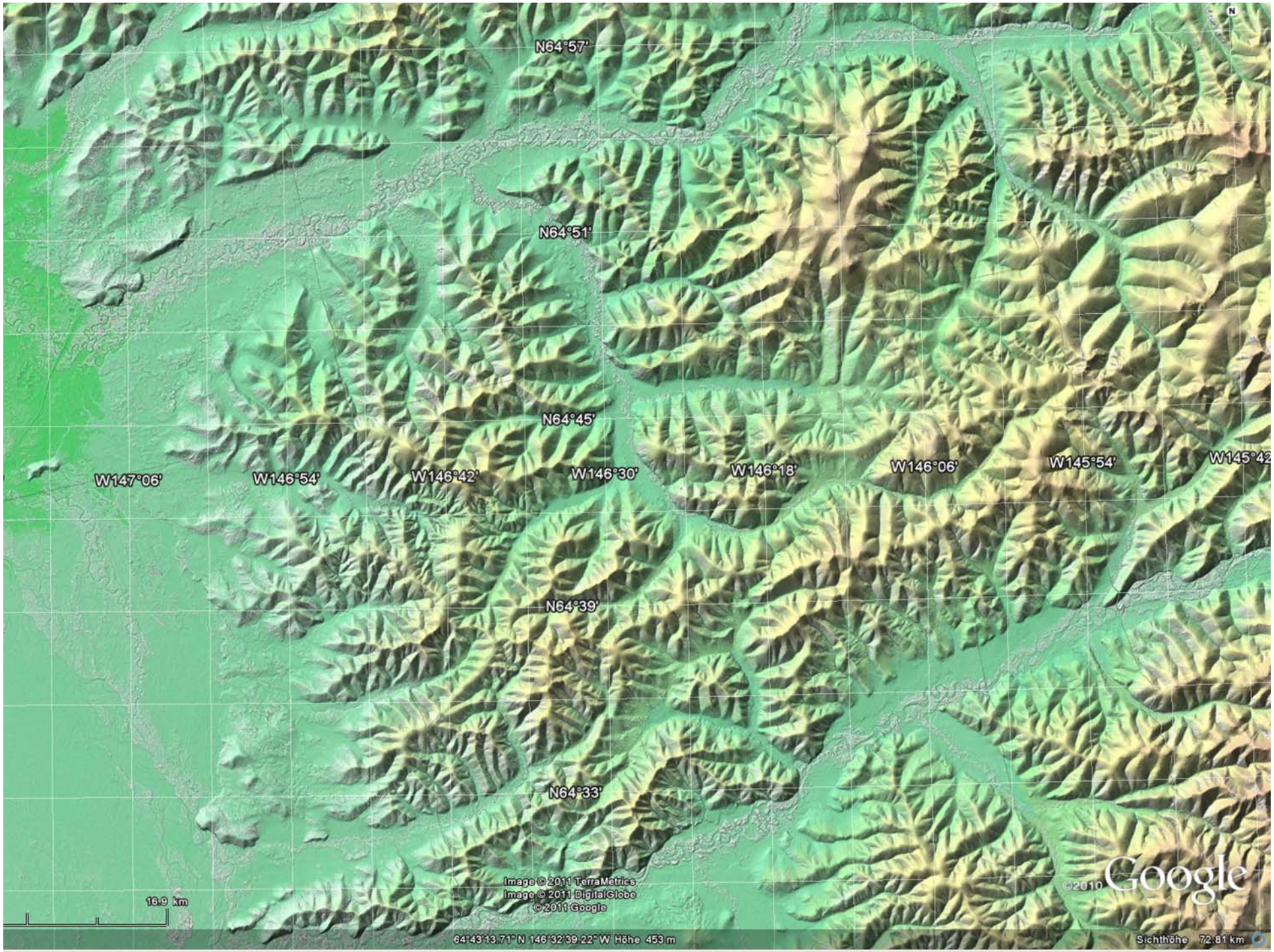
Alaska
(until 2011-10-26)



East Canada
(until 2011-10-26)

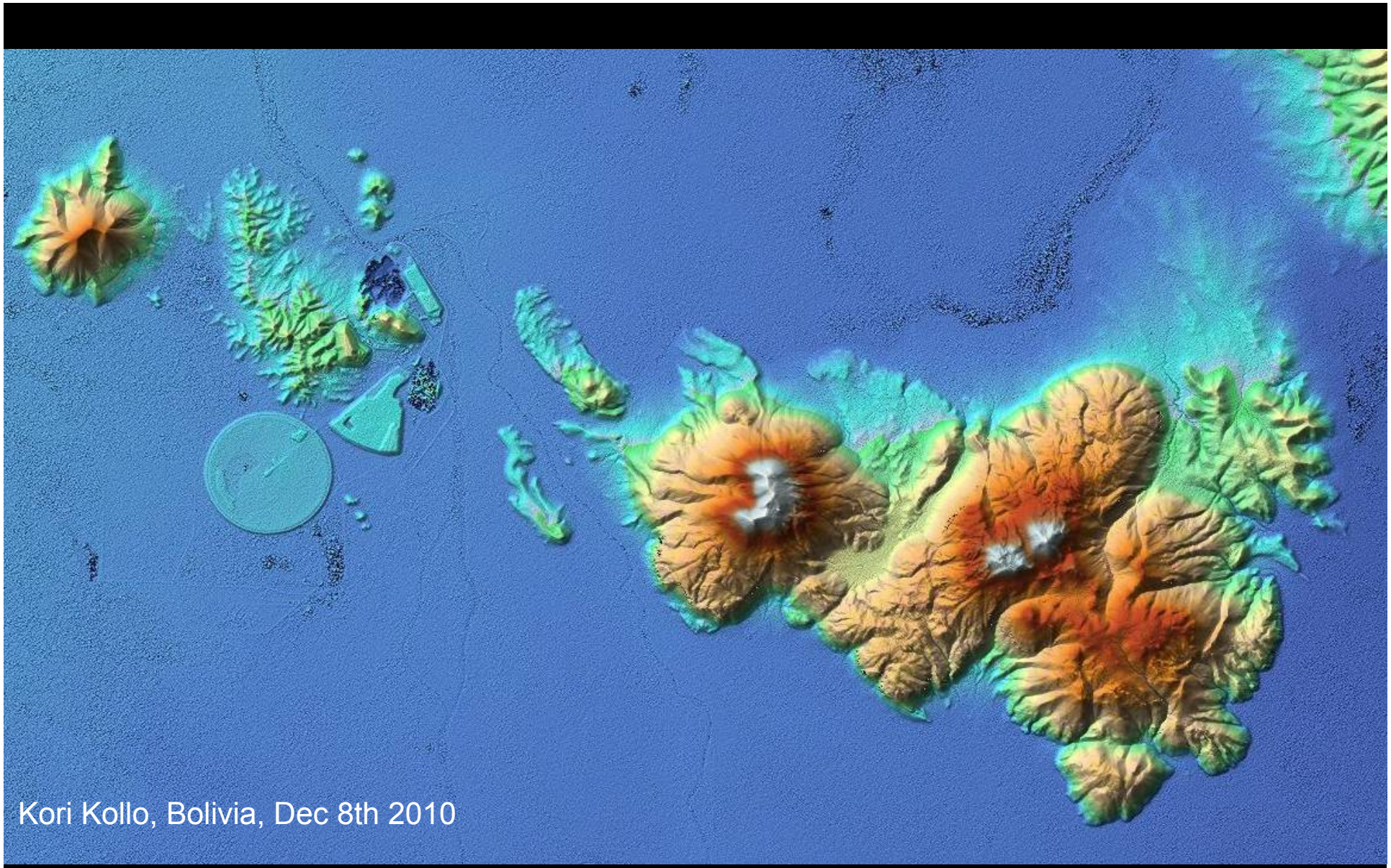

TanDEM-X Raw DEMs Close to Fairbanks
Mosaic of 11 TanDEM-X Data Takes
Acquired over Alaska
N65°45'
N65°15'
Fairbanks, Alaska, USA
N64°45'
W150°30'
W149°30'
W148°30'
W147°30'
W146°30'
W145°30'
W144°30'
W143°30'
W142°30'
W141°30'
W140°30'
N64°15'
N63°45'
N63°15'
122 km
Image © 2011 TerraMetrics
© 2011 Google
©2010 Google
64°23'03.86" N 146°19'43.84" W Höhe 535 m
Sichthöhe 513.15 km


N65°
Fairbanks, Alaska, USA
N64°30'
N64°
W148°30'
W147°30'
W146°30'
W145°30'
W144°30'
W143°30'
W142°30'
N63°30'
N63°
75 km
Image © 2011 TerraMetrics
Image © 2011 DigitalGlobe
© 2011 Google
Image © 2011 GeoEye
©2010 Google
63°56'15.44" N 146°00'24.44" W Höhe 446 m
Sichthöhe 319.34 km


N64°57'
N64°51'
N64°45'
N64°39'
N64°33'
W147°06'
W146°54'
W146°42'
W146°30'
W146°18'
W146°06'
W145°54'
W145°42
16.9 km
Image © 2011 TerraMetrics
Image © 2011 DigitalGlobe
©2011 Google
©2010 Google
64°43'13.71" N 146°32'39.22" W Höhe 453 m
Sichthöhe 72.81 km

Conclusions

- Integrated TanDEM-X processor ITP is up and running since one year and thus most reliably fulfilling its TanDEM-X duty. Operational data processing of global DEM data started after completion of bistatic calibration phase August 23, 2011.
- In-orbit sync pulse exchange and on-ground processing are reliable and accurate as expected.
- RawDEMs are free of time varying height errors potentially caused by oscillator offsets and drifts.
- Excellent performance of the bistatic synchronization.
- InSAR processing and raw DEM generation are robust, reliable, and accurate. The performance exceeds the expectations.
- We successfully pushed the limits of exploiting the outstanding absolute and relative bistatic geometric accuracy to support calibration, quality control and to become independent of any reference data in InSAR processing.
- ITP's radargrammetry and phase offsets became a workhorse for the bistatic system and baseline calibration process.



Kori Kollo, Bolivia, Dec 8th 2010

Thank You For Your Attention